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Can remote sensing estimate fine-scale quality indicators of natural habitats?

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ABSTRACT

Efficient management and conservation of natural habitats requires a thorough knowledge and sustained monitoring of their ecological quality. In recent years, several methods have been developed to assess the local conservation status in the field. These typically combine estimates of coarse-scale indicators, such as tree and grass encroachments, with very fine-scale indicators that require precise fieldwork, such as the number of key species present. We first tested whether coarse-scale field characteristics can provide information on fine-scale indicators. Then, this idea was extended to remote sensing techniques to derive estimates of fine-scale properties that cannot be derived directly by the sensors. The method was elaborated for two Natura 2000 heathland areas, combining field conservation status assessments of over 650 locations with remote sensing information derived from an airborne hyperspectral scanner image. Boosted regression trees using field estimates of coarse-scale parameters as predictors were able to explain up to 43% of the variation in the fine-scale indicators. When using remote sensing data, models performed only slightly less. Up to 35% of the variation was explained using remote sensing estimates of coarse-scale parameters as predictors, and up to 39% was explained when additional remotely sensed land cover data were included in the models. Although these rates are not high in absolute terms, model predictions for certain parameters were more precise than field estimates, especially for criteria with a high between-observer variability. These results clearly illustrate the potential of remote sensing imagery to derive information on the conservation status of habitats, even for fine-scale elements that are too small to be derived directly.

1. Introduction

1.1. Conservation status assessment

Deterioration of natural areas has a strong negative impact on the local biodiversity, and may put rare and threatened species at a serious risk. Many monitoring programmes have been initiated to detect such alterations, often in response to national and international obligations (e.g. the Vital Signs Monitoring by the National Park Service in the USA; monitoring programmes of various member states of the European Union related to the Habitats and Birds Directives). In most programmes, the required information is visually extracted from aerial photographs, in combination with field visits for a detailed description of the local situation (Allard, 2003; Aplin, 2005; Vanden Borre et al., 2011). In recent years, several methods have been developed to assess the quality of habitat patches in the field (e.g. Fancy et al., 2009; Parkes et al., 2003; T'jollyn et al., 2009). Parameters that are typically evaluated comprise structural characteristics (e.g. proportion of dead wood in a forest), disturbance-related criteria (e.g. grass and tree encroachment in open habitats), characteristics related to the floristic composition (e.g. number of occurring key species) and landscape configuration (e.g. connectivity and isolation) (Bock et al., 2005; Tiner, 2004). As all these parameters relate to specific properties of the habitat (Bock et al., 2005; Parkes et al., 2003; Søgaard et al., 2007), estimates of each individual indicator are desired, rather than combining them in one joint quality indicator (T'jollyn et al., 2009).

1.2. Field assessment

National and regional field monitoring programmes provide accurate indications of the actual conservation status of natural habitats, and they are definitely helpful to detect and follow pressures and threats on natural systems. However, field methods have some major drawbacks. First, a frequent wall-to-wall coverage of large areas solely based on fieldwork is highly unrealistic due to budget constraints. Moreover, field visits to inaccessible zones such

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as military terrains, large wetlands or remote areas are inherently difficult. Second, field mapping is relatively slow, and the digitalization and processing of field data from large areas can take up to several years. Third, despite the existence of strict rules for field mapping, between-observer errors clearly remain an issue (Hearn et al., 2011; Sykes et al., 1983), making it extremely difficult to compare and integrate results, let aside to quantify the occurring changes.

1.3. Remote sensing assessment: opportunities and limitations

Remote sensing techniques have often been suggested as valuable tools for mapping and monitoring natural areas. Based on (semi-)automated analysis of air- and spaceborne images, the accurate detection of changes is possible in nearly real-time (Stone, 2010). Additionally, vast areas can be covered simultaneously, and a wide range of automated image processing algorithms avoids observer bias. As a result, remote sensing has been successfully used for many ecological applications, such as detecting land-use changes, monitoring deforestation, estimating carbon sequestration, detecting vegetation stress,... (reviewed by Aplin, 2005; Horning et al., 2010; Kerr and Ostrovsky, 2003; Wang et al., 2010; Xie et al., 2008). Surprisingly, the use of remote sensing for accurate, detailed and complete conservation status assessment and monitoring of natural habitats, such as required in the European Natura 2000 context, is still rarely exploited (Vanden Borre et al., 2011, but see Förster et al., 2008 and Haest et al., 2010 for two recent examples). Possibly, a historical gap between the remote sensing and the nature conservation communities has caused a delay in the development of such applications (Asner et al., 1998; Wang et al., 2010). However, the limited capacity of current sensors to discriminate individual herbs at a species level still discourages many vegetation ecologists (Bradley and Fleishman, 2008). Indeed, discerning small and similar-looking structures belongs to the major limitations of current remote sensing (Lechner et al., 2009). Despite the advances in air- and spaceborne sensors, with an ever-increasing spectral and spatial range and resolution, and despite the parallel growth in data analysis approaches, the identification of small non-dominant plants, especially herbs, remains a huge challenge. Although recent developments in the domains of spectral unmixing and fuzzy classifications (Foody and Cox, 1994), super-resolution image reconstructions (Park et al., 2003) and data fusion may provide details on a sub-pixel level, it remains unlikely that individual herbs will be recognizable from the sky in the near future.

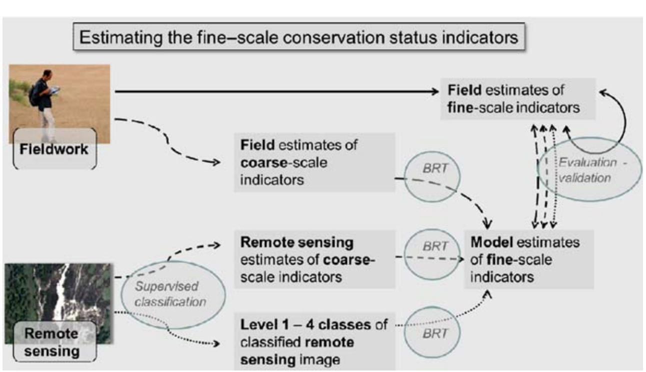

Fig. 1. Pathways to derive fine-scale indicators from fieldwork and remote sensing imagery. Fine-scale indicators were estimated directly in the field (solid line), or were modelled with boosted regression trees (BRT) using either field estimates of coarse-scale indicators (long dashed line), remote sensing estimates of coarse-scale indicators (short dashed line), or all landcover classes from a classified hyperspectral image (dotted line). For validation, model estimates were compared to field estimates, while the between-observer variation was documented to validate the field estimates themselves.

But do we really need extremely detailed imagery for a complete conservation status assessment? Or in other words, are fine-scale indicators really unmeasurable with current remote sensing techniques? Many of these indicators are probably correlated with coarse-scale parameters, and hence, they can indirectly be derived from indicators that can be measured with remote sensing. To investigate this idea, we first determined to what extent the coarse-scale field characteristics could model the more subtle fine-scale indicators, based on an extensive dataset of conservation status assessments of heathland patches visited in the field. In a second step, we checked if these fine-scale parameters could also be predicted by remote sensing estimates of the coarse-scale characteristics. Finally, we tested if the inclusion of other land cover data from remotely sensed origin could further improve the model performances (see workflow of the study in Fig. 1).

2. Materials and methods

2.1. Heathland ecosystems

In this article, we focus on the conservation status assessment of four typical habitat types of West-European lowland heathland: dry sand heaths with *Calluna* and *Genista*, inland dunes with open *Corynephorus* and *Agrostis* grasslands, European dry heaths with *Calluna*, and Northern Atlantic wet heaths with *Erica tetralix* (Table 1). As a result of drastic changes in agricultural practice (Webb, 1998), these semi-natural habitats have shown a dramatic decline since the early 19th century. Heathlands are now largely restricted to nature reserves, military zones and remote areas. Despite their legal protection under the European Habitats Directive (92/43/EEC), atmospheric nitrogen deposition, desiccation, tree and grass encroachment, and invasive species continue to impose severe pressures on the remaining heathland ecosystems. Consequently, their ecological value is further decreasing, potentially resulting in a rapid change of the conservation status (De Blust, 2005). The impact of these pressures can be measured in the field by evaluating several "quality indicators" (e.g. Ellmauer, 2005; Søgaard et al., 2007; T'jollyn et al., 2009; Verbücheln et al., 2002 and Table 1). For example, a dry heathland in good condition is characterized by a rich structural variation with young and old heather plants (*Calluna vulgaris*), which can be evaluated by verifying the presence of the different age classes of the shrub (T'jollyn et al., 2009; Verbücheln et al., 2002).

2.2. Fieldwork

In the summer of 2009, we evaluated the local conservation status of habitat patches in two Natura 2000 heathland sites in northern Belgium ("Kalmthoutse Heide" and "Klein en Groot schietveld"; 51°22′N, 4°27′E). First, a set of 559 sample points were selected following a stratified random design, taking in-between distance and vegetation type into account. Around these points, one or more vegetation patches were delineated based on the guidelines for European habitat surveillance ("BioHab", Bunce et al., 2005, 2008), which resulted in a total of 671 plots of 0.37 hectares on average (range 0.04–1.0 ha). For all these patches, the Natura 2000 habitat type was defined and the quality indicators relevant for that habitat type were estimated (Table 1). Vegetation cover was determined visually, either on a continuous scale (but showing a typical bias towards multiples of ten), or on a Tansley scale (see T'jollyn et al., 2009 for details). T'jollyn et al. (2009) provides relevant indicators and corresponding threshold values to evaluate the conservation status of all Natura 2000 habitats, including heathland habitat types. It was approved by policy makers, conservation scientists and land-using stakeholder representatives